CORE organic DOMINO

DELIVERABLE N. 3.6

DYNAMIC SOD MULCHING AND USE OF RECYCLED AMENDMENTS TO INCREASE BIODIVERSITY, RESILIENCE AND SUSTAINABILITY OF INTENSIVE ORGANIC FRUIT ORCHARDS AND VINEYARDS

YEARLY REPORTS OF BIODIVERSITY DATA (2019)

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Introduction

The challenge represented by weed management has been indicated as one of the mayor constraints in conversion into organic management (Bond & Grundy, 1998). Beside the limitation imposed in the use of chemical tool, the whole approach in organic weed management should be substantially different. Full weed eradication shouldn't be a goal (Blake, 1990), there are obviously conflicts between completely weed eradication and other aims of the organic system (Mattsson et al., 1990; Colquhoun & Bellinder, 1996). Despite the initial positive effect of a mechanic weed control due to organic soil matter mineralization, heavy negative outcomes will be detrimental for soil physical, chemical and biological fertility.

In the last decades, a more holistic approach intended to increase the sustainability of the agronomic practices by increasing the biodiversity has characterized a rising part of the organic scenario (Mia et al, 2020a, b). Nowadays, a further challenge for the organic farmers should be to move from the goal of a "greater biodiversity" to the setting of a better diversity, finalized to the achievement of precise agroecosystem services.

Weed community composition in orchard agroecosystem depends on how the local biodiversity is selected and favorited by environmental, biotic, and especially management factors, that act as "environmental filters" (Gotzenberger et al., 2012; Borgy et al., 2016). Some of the practices, like tillage, act more than others as strong filters (Barberi et al., 1998). For these reasons, an integrated or ecological weed management requires precise knowledges on the effect of management practices on the weed population composition (Bastiaans et al., 2000).

An indiscriminate increase in biodiversity in the ground cover, as well as in the soil, due to the inclusion of naturally selected species, could induce competition and disequilibrium within the orchard, hardly tolerable in a productive layout. An innovative approach would manipulate biodiversity looking for an improvement of services and functions in the acro-ecosystem.
Diversification is recognized as a factor promoting system resilience; nevertheless, a generical increase in biodiversity is not in itself a guaranty for the improvement of the economical sustainability of the organic practices (Barberi et al 2016).

The challenge evolves toward the identification of species combination able to provide services to the system and to maintain competition to a not detrimental level. It would be possible to intensify organic agriculture by developing strategies for targeted exploitation of biodiversity. Neri et al (2020) used a living wild strawberry mulch in vineyards to control the other weed competition without any detrimental effect on grape yield. Bender et al. (2016) proposed an interesting model on the contribution to input substitution by endogenous resources (Figure1).

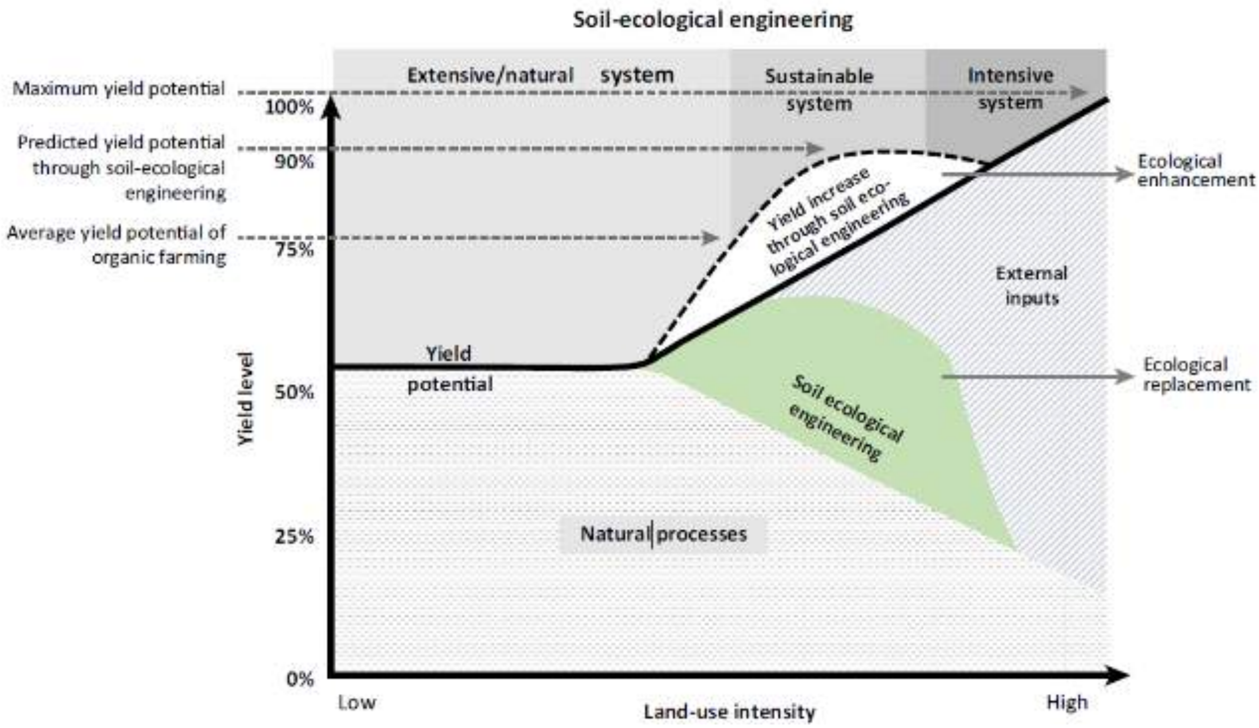

FIGURE 1: Conceptual model showing the contribution of external resource inputs and natural biological processes to an ecosystem function, in dependence of land-use intensity

At low land-use intensity, yield is low and sustained by natural biological processes. With increasing land-use intensity, dependence on external resource inputs increases and the contribution of natural biological processes decreases. Yield is highest under intensive management with a high level of external resource inputs. Soil ecological engineering (green) complements the contribution of natural biological processes and can partly replace external resource inputs, therefore either maintaining yields while reducing external inputs (ecological replacement) or enhancing yield without enhancing external inputs (ecological enhancement) (Bender et al. 2016).

DOMINO'S ACTIVITIES

All the research groups involved in the DOMINO project contributed in 2018-2020 to the definition of best practices, locally tested, for sustainable weed management. The goal was to reduce soil tillage, assure a permanent soil cover thus managing weed competition within a physiologically sustainable level. A further goal was to include species providing agroecological services and valorize for the same aim local biodiversity. In 2019-2020 some results were added to the studies of all the partners.

Living mulches: criteria for the selection of suitable species

Several local spontaneous or cultivated species have been tested for under-the-row ground management.

The choice for the species to be grown on the row has been done considering several aspects:

a) the species is adapted to environmental and agronomic condition
b) the species could provide an additional source of income
c) the species could provide some agronomical services (e.g. phytosanitary activities)
d) the species could provide a multifunctional activity

The selection of species issued from local biodiversity provides significant advantages in terms of plant resilience. Looking at local species behavior will also help in identify plants with the higher soil cover capability. When considering the additional source of income, **officinal plants** appeared as a potential target as well as horticultural species. A strong interest and market opportunity are recognized for organic officinal plants in several countries and at EU level. Discussions with producers of officinal plants have pointed out that the possibility of growing plants in a shadow environment, like that of a fruit tree row, is an added value for the market thus increasing product quality.

Poland (INHORT): experiences from continental climate.

The experience of 2018

Among species that prefer such shadow environment is *Hierochloë australis* – the plant used to produce a unique kind of aromatized vodka typical of Poland: "zubrówka". Furthermore, there are species which can be harvested very soon in the season (i.e. *Alium ursinum*), thus not causing competition with the fruit trees. Likely, there are species which are also quite well covering the ground, so highly reducing the competition from weeds (*Alchemilla vulgaris*, *Galium odoratum, Veronica officinalis)*. Some of them, normally considered as "weeds", can be valorized as officinal preparations.

Species able to provide agronomical services were also selected to sustain plant protection or plant nutrition. Soil-borne pests are quite difficult to control even in conventional orchards, and organic farming limitations in the use of pesticides needs to be overcome with new solutions. The availability of plants that produce specific **root exudates** containing compounds that can interfere with soil pests is thus an opportunity that has been considered when selecting species to be grown on the row. Among them two have been considered, *Tagetes* sp. and *Taraxacum officinale*. The former is highly **repellent of parasitic nematodes**, while the second results to be preferred by white grubs (larvae of May beetle), thus reducing the risk of damaging tree roots. However, an unexpected positive effect of some officinal species on above ground pests was observed in preliminary trials established, during the project, to verify the feasibility of certain herbs to be grown on the row: a two-fold **increase of predatory mites** on the apple leaves was determined when growing nasturtium and mint. Dandelion is also requested for herbal preparations, thus making this plant a potential multifunctional species (phytosanitary and cash crop). We have also considered to test other species, which can be useful for weed control and production of raw materials for uses in phyto-cosmesis or food preparations, such as *Potentilla anserine, Melittis melissophyllum* and *Symphytum officinale.*

To improve plant nutrition, trials are established testing a modified “sandwich system”. Microclover has been planted along the tree row. This species has an initial slow development, but it is resistant to soil pounding by machines and do not compete much for water and nutrients due to its small size.

As a weak point, it should be stressed that not all species performed equally well in reducing weeds infestation. Nasturtium and mint, despite their promising characteristics did not succeeded in competing with weeds so that their relative abundance progressively decreased, in the parcels.

In the interrow, a mixture of seeds has beenen sown. This is composed by a gramineous (for example *Festuca ovina*, which covers well the soil, but grows little and is highly resistant to pounding) and a leguminous, again to increase N supply. We are testing new leguminous species (Kura clover - *Trifolium ambiguum*, and *Galega orientalis*) that have proved to be interesting in Poland also for the production of feedstuff.

The experience of 2019

The species were selected on the basis of the results of the preliminary trials of 2018 at Inhort and of other partners. Only two of the previously tested species (mint and garden nasturtium) were further considered in this trial together with a third species tested in Germany and Italy (wild strawberry). In total 11 species were utilized and selected for their potential use as secondary crop, crop protection or soil phytoremediation properties. For the selection, also the following characteristics were considered: the reduced competition with apple trees, the competition with weeds, the market need. Among them, 10 resulted to perform in a satisfactory way, with some interesting, unexpected, outcomes: the species *Viola odorosa* was able to maintain the row almost free from weeds probably due to an allopathic mechanism. Data about soil and above-ground fauna were also collected showing also in this case very interesting results useful for the analysis planned under Task 6.1.

A trial for inter-row and row management (Task 3.2) using mixtures formed with Festuca ovina and one of four leguminous species (*Trifolium ambiguum, Galega orientalis, T. repens* normal type or micro type) was set up. The unusual dry season has initially jeopardized the establishment of the trial, but the cover crops have partly recovered during the last part of the season. Nevertheless, it is planned to renovate the plots of the two new leguminous species in the next season. The soil analyses planned to follow the dynamic of nitrogen availability have been performed and are showing a quite interesting trend which will be assessed in combination with the data of soil biodiversity.

Three trials have been set in commercial orchards, testing some of the species selected for row management. The monitoring of the effects on major pests was performed.

Switzerland (FIBL, Frick)

At FiBL the demonstration trial with the living mulch in the tree row has been started in April 2019. Following six species were used as living mulch: *Fragaria vesca*, *Hieracium aurantiacum*, *Hieracium lactucella*, and *Potentilla reptans*, white clover, and micro clover. *Hieracium aurantiacum*, *Hieracium lactucella*, were sown in April, grown in the greenhouse, and later planted in May into the tree row, along with the strawberries (6 plants per meter). *Potentilla reptans* was already occuring naturally at the site and was transplanted into the tree row (also 6 plants per meter). White clover and micro clover were directly sown into the tree row in May (2 g/m^2) but could not establish due to the drought. They were re-sown in September, but once again could not establish. Selective weeding was performed once a month from June until September (in total and on average around 20 min per square meter). End of June all living mulches covered between 25 and 40% of the tree strip, with *Potentilla reptans* being the most covering followed by *Fragaria vesca* and *Hieracium lactucella*, and *Hieracium aurantiacum*. End of July *Potentilla reptans* covered 90% of the surface, whereas the other living mulches covered only 50 to 60% of the surface. Mid November, *Potentilla reptans* and *Hieracium lactucella* almost covered the whole tree strip, *Hieracium aurantiacum* covered around 75% of the tree strip, and *Fragaria vesca* around 65%. The plots with *Fragaria vesca* showed the most weeds compared to the other plots.

FIGURE 2: The naturally occurring Potentilla reptans as living cover in October 2019.

FIGURE 3: From top: Fragaria vesca, Hieracium aurantiacum, and Hieracium lactucella in May 2019 (left) and October 2019 (right).

The use of legumes

The trial with the legumes as living mulches in the inter- and intra-row has been started in April 2019. Peas as well as white clover and micro clover have been sown end of April in the intra-row for the peas respectively the inter-row for the clover. The peas developed well and were mulched in July. The clover however did not develop because of a drought and was sown again in September, but once again did not establish. Soil Nmin analyses were performed during the season from April until October.

FIGURE 4: The peas in the intra-row end of May 2019

Germany (Stuttgart)

The demonstration trial to enhance biodiversity in the tree row in apple orchards was set up at the KOB in 2018 with wild strawberries and peppermint. The establishment of the strawberries was partly problematic, so some plants had to be replanted in July 2019. The ground cover was rated at three points in time for the strawberries and mint, as well as for the weeds. To reduce overgrowth of weeds, the plots were weeded by hand two times. The strawberries showed lower competitiveness against weeds than the mint. The mint grew to a height of 1 m and was cut back in August and October.

The use of legumes

The trial on leguminous mulches in the inter row as internal nitrogen source in apple orchards was delayed due to the insufficient establishment of the clover in autumn 2018 resulting from extremely dry weather conditions. Clover was therefore reseeded in spring 2019 and established in summer 2019 in the inter row. Measurements of biomass production and nutrient content of the clover as well as soil Nmin are therefore postponed to 2020.

A Master thesis was done on the current situation of the usage of the inter row and its potential as internal nutrient source to gain additional information. Farmers in the Lake Constance and the Freiburg region were interviewed, soil samples were taken, and throughout the season 2019 the biomass production in the inter row was measured as well as the nutrient content (C, N, P, K, Ca, Mg) of the cuts, transferred to the tree row. Differences in management strategies between farmers could be observed in terms of number of cuts and the establishment of flower strips. The nutrient content of the cuts fluctuated during the year. The thesis will be submitted in 2020, full data will be available then.

At the Competence Centre for Fruit Growing Bavendorf a demonstration trial has been started in October 2018 with wild strawberries (*Fragaria vesca*) and peppermint (*Mentha x piperita*) planted in the row under apple trees on M25 with a spacing of 3.6 m. The strawberries were planted with a density of 9.4 plants m^{-2}, the peppermint with a density of 4.4 plants m^{-2}, each on 10.8 meter length. The trees are planted in metal baskets to prevent damage by mice. During the vegetation period, the ground cover of the crops as well as the weeds will be measured two to three times and the results will be compared with the hoed and untreated control (Figure 5).

Wild strawberries in the row

Peppermint in the row

FIGURE 5: Demonstration trial in October 2018 and in spring 2019.

South Tyrol (Northern Italy)

Eight different species were pre-test at the Laimburg research Centre and their performance had been compared with grassed and tilled ground. Below the main traits considered for species selection and the full list of species selected for their interesting characteristics (Tables 1 and 2).

TABLE 1: Relevant features in living mulches species and relative scoring

Wanted features	***** or ****	*****	**-**	**+* or +**** (poor conditions improved up to **)
Height	< 45 cm	45 - 65 cm	> 65 cm	+ mulching
Light requirement	low	medium	high	
Reproduction potential	stolons/high seeds production	low or not mature seeds production	no seeds/stolons production	
Competitiveness against weeds	high	medium	low	+ stale seed bed
Competition with trees	low	medium	high	
Beneficial insects	predators or pollinator	no data	low attractiveness	
Pests	repellent or not attractive	no data	high attractiveness	
Drought resistance (orchard conditions)	high	medium	low	+ irrigation (only after sowing)
Nutrients requirement	low	medium	high	+ moderate fertilization

TABLE 2: Characteristics of the main species selected as living mulches

	Height	Light requirement	Competitiveness against weeds	Competition with trees	Beneficial insects
Living mulch					
Portulaca oleracea	***	***	***	?	
Tropaeolum majus	***	***	***	?	
Potentilla reptans	***	***	**	?	
Galium mollugo	***	***	***	?	
Achillea millefolium	***	***	*	?	**
Trifolium repens	***	***	**	***	
Fragaria vesca	***	***	*	?	
Euphorbia helioscopia	***	***	**	?	
Sanguisorba minor	**	**	***	?	
Glechoma hederacea	***	***	***	?	
Salvia pratensis	***	**	*	?	
Trifolium resupinatum var. resupinatum	***	**	**	***	

	Pests	Drought resistance	Nutrients required	Reproduction potential
Living mulch				
Portulaca oleracea	**	***	***	***
Tropaeolum majus	**	+*	**	Na
Potentilla reptans	**	**	***	***
Galium mollugo	**	**	***	**
Achillea millefolium	**	***	***	**
Trifolium repens	**	***	***	**
Fragaria vesca	**	-	***	***
Euphorbia helioscopia	**	***	***	**
Sanguisorba minor	**	**	***	Na
Glechoma hederacea	**	***	***	***
Salvia pratensis	**	***	***	*
Trifolium resupinatum var. resupinatum	**	**	***	***

In May 2018 LAIM performed a screening aiming to evaluate the potential of 16 species (single or in a mix) as cover crops in the orchard and 16 species (single or in a mix) in the vineyard. The selection of these species was done in function of the possible ecosystem services that the single species should provide (e.g., nitrogen fixation, high biomass production, control of the weed growth, attractivity for beneficial insects, etc.), besides the live mulching function. From the results obtained in 2018 a further selection was done, to test the most promising species in a randomized block design with four repetitions per treatment. The species were selected in function of their light and water requirement, their competitiveness with fruit trees and with the other spontaneous species, their potential to grow and cover the soil, their physical characterize (e.g. height) and the results of the previous screening. During the 2019 trial only four species/mix showed satisfactory growth (i.e., *Trifolium repens*, *Gallium album*, *Trifolium resupinatum* and the mix *Trifolium repens, Gallium album*, and *Achillea millefolium*) but the trials of 2020 – 2021 will still proceed with the same species tested in 2019. All the other tested species, even if at the beginning of the season showed great potential (e.g., *Potentilla reptans*) they were not able to stop the development of *Echinochloa crus-galli*, one of the most aggressive weeds we found in our field.

Data about nutrients in the leaves, mineral nitrogen of the soil, fruit production and quality of the harvest were collected during the whole year and will be evaluated also in 2020. The results obtained in the vineyard are not satisfactory yet, as the plants growth was weak, and the selected species were not competitive enough against the weeds. Furthermore, mole crickets damaged many of the selected species (in particular *Achillea millefolium*, *Sanguisorba minor* and *Potentilla reptans*).
No significant differences were found for the macronutrient content in the leaves of July, while Iron was significantly higher in the mix *Trifolium repens*, *Gallium album* and *Achillea millefolium* compared to the tilled soil. The mineral nitrogen was quite variable as influenced by the different soil management effectuated in the function of the sowing moment required by the different species, but as expected legumes increased or maintain constant the mineral nitrogen into the soil during the two sampling campaigns, while other species sharply decreases the amount of mineral nitrogen available in the tree line. Significant differences were also found during the harvest in the tree production, but further year assessments are required to establish if the live mulching could increase/decrease the fruit production.

The inter-row species selected for the green manure trial performed at Laimburg were tested in the orchard and in the vineyard. No selected species used as single species or in a mix showed satisfactory results in terms of biomass development and coverage of the ground. The weed pressure in the orchard was too high and the sowed species were not competitive enough. Moreover, the soil of the orchard was quite compact and did not allow the water to drain. The water excess was a second important limiting factor in our green manure field trial, which invalidates the experiment. The soil analyses planned to follow the dynamic of nitrogen availability were done only at the beginning of the experiment, as there was no necessity to monitor this unsuccessful trial.

Central Italy (UNIVPM)

Living mulches with horticulture species

Based on previous successful experiences, at UNIVPM, several species of strawberries have been tested in different agronomic condition in young rainfed apricot orchards in low hills close to Adriatic see (Ancona, Italy). While a wild strawberry species was established in rainfed vineyards in the internal high hillside (Castelraimondo, MC, Italy).

Highly vegetative species selected for their stoloniferous aptitude maintained a soil cover exceeding the 40% during the first summer and produced an interesting number of stolons and new plantlets. In late winter, soil cover for those species exceeded the 50% (Figure 6).

FIGURE 6: white strawberries soil cover in February 2019

FIGURE 7: potentilla soil cover in February 2019

The same excellent performance was recorded for the living mulches with *Potentilla ssp.* A 60% of soil cover has been reached in this case, with several soil spots showing a 100% of covering by the mulches (Figure 7).

Wild species of strawberries, rather adapted to shadow condition, suffered instead some summer drought stress in calcareous soil in low hill, in the absence of complementary irrigation. After an initial soil cover percentage ranging at around 30%, one month after transplanting, the soil cover decreased during summer and a relevant percent of plantlet failed. A remaining 10% of soil covered by mulching was recorded during autumn and winter. The recovery of those species was hard during the following spring, due to a large population of weed development in the parcel.

Mulches performances strongly differed due to soil and climatic caratteristics as well as due to soil management practices. In fresh, acid soils in the internal high hills, in the presence of abundant rains during spring and a mild summer wild strawberries doubled the percentage of soil covered in 4 months moving from an average 30% to a 70%. In those condition the ideal number of plantlet to be installed under the main crop was one for each side of the grapevine. Variant with a double number of plantlets did not differed accordingly in performances thus indicating that, in the presence of favourable conditions to runners production, a low initial investment would assure the success and the efficacy of the mulching. A labor investment of about 30 hours/ha was estimated for mulching installation in favourable condition. An initial investment of 0,10 cent/plantlet will be required, thus meaning a cost of about 1.000€ for a pilot surface of 1 ha. It has to be highlighted that the high production of runners will allow to self-produce, within one year, the material for any further transplant. The harvest and transplant of the plantlets can be managed by using internal labor in rainy days thus allowing a great compatibility with the other activities scheduled. Mulches resulted particularly helpful especially in the management of the area surrounding the trunk harder to manage otherwise (Neri et al. 2020) (Figure 8) .

No further extra costs were required other than the management routinely required by the vineyard. A production of 1000 Kg/ha was estimated for the second year after installation, thus fully covering the installation cost. The added value of the mulching as to be considered also in terms of social and commercial perception of the agronomical practices by the consumers (Figure 9).

FIGURE 8: Soil fully covered under the vineyard can. No further soil management will be needed after strawberry full set.

FIGURE 9: Strawberries adopted as living mulches, in the home page of the farm as commercial claim on the sustainability of the agronomic practices.

The experience of 2019

The Colle Stefano winery (Castelraimondo, MC, Italy) in high internal hillside of Marche region, hosted the trial managed with UNIPM about the wild strawberry of Sibillini's mountains as living mulching in the row. Three years after strawberry planting, the soil covering by strawberries and weeds was measured. The treatments were 0, 2 and 4 strawberry plants per vine. All treatments were tilled with a horizontal blade that cuts the soil to a depth from 5 to 15 cm in order to cut the roots of the weeds that spread in depth with taproot.
The results collected so far are very encouraging, indeed the coverage of the strawberry in April 2020 was about 90% for both the treatments. The blade and strawberry combination is a winning strategy in this environment, in fact there is a decrease of weeds for treatments with strawberry (Figures 11-12).

In the other trial carried out at the low hillside at the experimental university farm in Ancona-AN trial on the tree row of apricot orchard white strawberry and potentilla showed a good establishment compared to other strawberry cultivars and wild species. This result can be explained by the provenience area of the wild strawberry (Sibillini Mountains where there are more summer rains) and the less competition of the cultivated strawberries (Figure 11).

The same orchard in Ancona hosted the inter-row cover crops trial, where, in autumn 2017 it was sown a mix of Festuca rubra (70%), *Trifolium spp* (20%) and *Sinapis alba* (10%). In September 2018, we carried out a syntaxonomic classification that shown a maturity index of 5% higher in the seeded row than in the control row.

FIGURE 10: Living mulch along the grapevine row by wild strawberry during the winter.

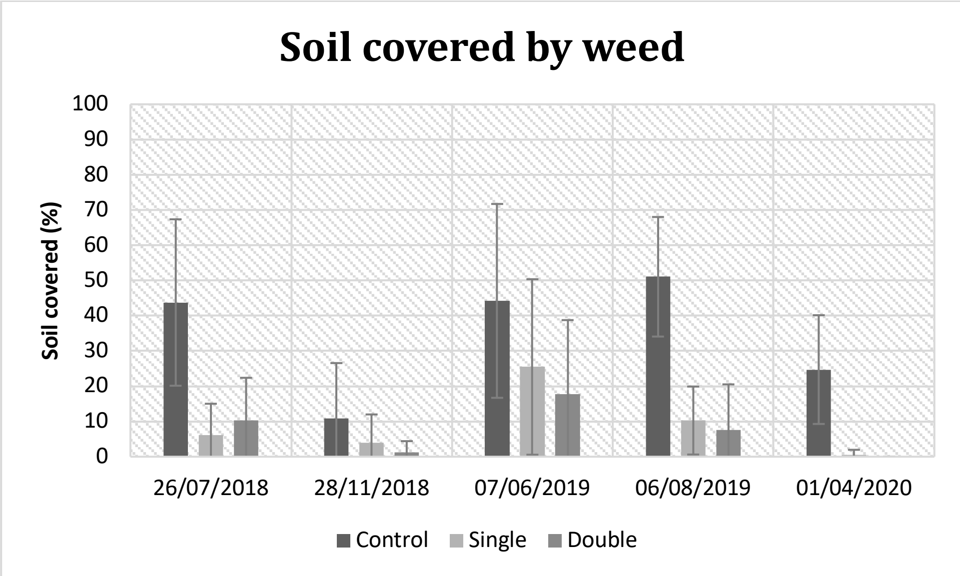

FIGURE 11: Percentage of the soil covered by weed according to single (2 strawberry plants per grapevine) and double (4 strawberry plants per grapevine) mulching density (mean±st. dev.).

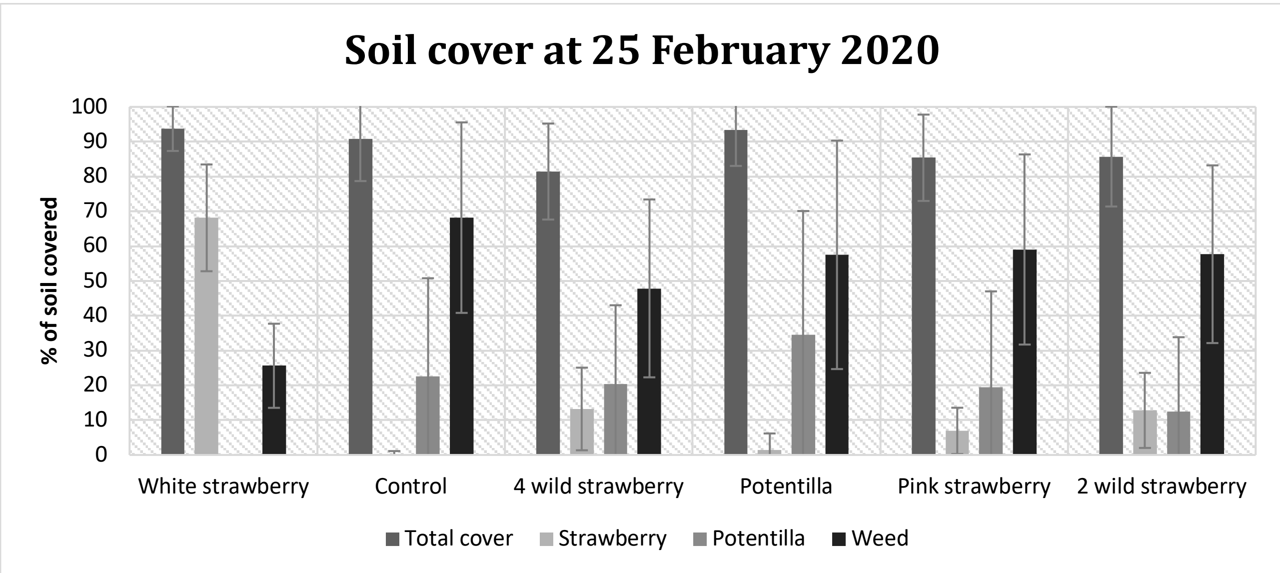

FIGURE 12: Percentage of the soil covered by weed, strawberry, potentilla and total for each treatment (mean±st. dev.).

Selective weeding: engineering local biodiversity

The valorization of local biodiversity in soil cover management was the goal of a selective manual weeding applied in an apricot orchard in the low hillside at University experimental farm in Ancona.

2 months after installation the spontaneous weed population was manually selected in order to eliminate by uprooting just competitive, tap root and taller species. 8 months after manual intervention the average and maximum weed height were 50% lower in weeded parcels (Figure 13) thus reducing competition and inducing significant advantages in the main crop development resulting in a 20% higher trunk caliper relative growth rate. A significantly reduced incidence of highly competitive species was still appreciable after 10 months.

FIGURE 13: Weed height in control (left) and selectively weeded (right) parcels

France (CTFIL)

Perennial plants, dwarf lawn and green manures for the French organic apple orchard

In southwestern France, at the Ctifl Center in Lanxade, the choice was made to proceed in two stages. A large panel of ground covers selected for their expected ecosystemic services are first experimented in an open field trial. The purpose of this first step is to begin to verify the effectiveness of these ecosystemic services, to establish the ability of these ground covers to adapt to local soil conditions, to examine their compatibility with the apple tree growing calendar, and finally to begin to establish the way of managing these covers. It is only in a second step that a small choice of these covers will be selected (some for implantation on the row and others for interrow) and then implanted in an organic apple orchard of the Story® cultivar, to continue to study them over time.

The “open field ground cover assessment trial” was established in October 2018, first with 15 species or mixes of ground cover species, and then completed in spring 2019 with 11 other species or combination of species, all implemented at the rate of 3 replicates of 25 m² each. The list of these treatments is given in Table 3; among these, 13 are intended for implantation on the row and 13 for the interrow (12 legume-based green manures and a flowery mixture).

TABLE 3: Ground covers tested in the pre-screening field trial in Périgord, France.

		HERBISTATIC EFFECT		SOIL IMPROVMENT		PESTS & DISEASE CONTROL			ADDITIONAL INCOME	
	Implantation method (TP : transplant plugs ; S : seedling)	Short tapering ground cover	Allelopathic properties	Beneficial effect on nutrition	Beneficial effect on soil structure	Repellent effect on pests	Nematicide action	Pest antagonist host species	Edible crop	Aromatic plants
Mentha spicata	*TP*		X			X				X
Sagina subulata	*TP*	X								
Hieracium pilosella	*TP*		X							
Melissa officinalis	*TP*									X
Thymus hirsutus	*TP*	X	X							X
Potentilla verna	*TP*		X							
Soleirolia soleiroli + WMDC	*TP*	X								
Scleranthus biflorus + WMDC	*TP*	X								
Fragaria vesca + WMDC	*TP*		X						X	
Fragaria moschata + WMDC	*TP*		X						X	
Tagetes species + WMDC	*TP*		X				X			
White micro-dwarf clover (WMDC)	*S*	X		X						
Dwarf alfalfa	*S*	X		X						
Trifolium fragiferum (1) ❖	*S*	X		X	X					
Oats / Vetch / Berseem clover ❖	*S*			X	X					

Dwarf and intermediate white clover, trefoil, alfalfa lupulina, incarnate clover 💧❖	*S*			X	X					
Oats / Fababeans 💧❖	*S*			X	X					
Lupin / Forage peas / Vetch 💧❖	*S*			X						
English Ray Grass / Tall fescue ***REF*** 💧❖	*S*				X					
Phacelia / Vetch / Triticale 💧❖	*S*			X	X					
Mustard / Vetch / Triticale 💧❖	*S*			X	X					
Vetch / Faba bean / Mustard / Triticale 💧❖	*S*			X	X					
Incarnate clover 💧❖	*S*			X	X					
Soybean 💧❖	*S*			X	X					
Inoculated soybean 💧❖	*S*			X	X					
Mixture of 25 field flowers 💧❖	*S*							X		

Establishment period: 💧 *autumn 2018* 💧 *spring 2019* - ***Destination:*** ▯ *row* ❖ *interrow*

Providers : BARENBRUG - Pépinières LEPAGE - Pépinières FILIPPI - Atelier du Végétal - Pépinière Ribanjou

The choice of the species to be tested was done considering four criteria: (1) their herbistatic properties (allelopathic species; short-growth tapering species); (2) their expected positive action in pest protection (repellent species; beneficial insects and mites host plants); (3) their benefic effect on soil functioning and their nutritional potential for the trees; (4) their ability, in addition to one of these criteria, to generate an additional income for the farmer. For the latter objective, three aromatic herbs were chosen – *Thymus, Mentha, Melissa* – and three fruiting species – *Fragaria vesca* and *Fragaria moschata*.

The species cultivated as green manure were cut at the beginning of May, two weeks after flowering, and then mulched on adjacent strips of bare soil to assess their nitrogen release. Among the green

manure mixes tested, those consisting of annual species were managed on a rotational basis, as successive crops, chosen in order to supply the fertilizer needs of apple trees during their most active demand period, from spring to the end of August. Thus, a sowing of soybeans followed the mixtures Oats + Fababeans, Lupin + Forage peas + Vetch and Oats + Vetch + Berseem clover; soybean was chosen for its ability to produce a high level of biomass, and therefore, we hoped so, to release large amounts of nitrogen.
However, the perennial mix « MULTIFLORE LD » (White clover + Trefoil + Alfalfa lupulina + Incarnate clover) was cut and mulched on the side, but was not followed by another sowing, in order to determine its capacity to maintain itself and restore enough nitrogen by successive cuts.

A series of observations were made along the year 2019 on this trial: (1) flora and fauna biodiversity measurements (percentage coverage by planted or sown ground covers and spontaneous flora, earthworm counts by mustard test, abundance measurements of soil beneficial fauna by using Barber traps); (2) soil status measurements (nitrogen balance at 30 cm below the surface, soil moisture, infiltration capacity); (3) cover growth measurements (height and biomass); (4) work times and input costs recording.

Ground covers development dynamics

Observations made on the first batch of ground covers species, planted or sown in the fall, showed that the speed with which species occupy the space is an important factor in their ability to slow down weed development.
Thus, the two dwarf lawns tested – white micro-dwarf clover and dwarf alfalfa – kept a very nice appearance until mid-April, and then allowed just few fast-growing weeds to escape, such as rumex or groundsel. As well, the green manures sown at high density in October 2018, remained clean beyond their flowering stage, with very good biomass production, varying according to the potential of the mixed species. But in contrast, the perennial species tested for their allelopathic properties, and planted at a rate of 6 plants per m², didn't show, in this first spring, any ability to hinder the germination of spontaneous flora or its spread (Figure 14). Even if most of these perennials were chosen for their stolon propagation mode, only a very small extension of these plants was observed during this first springtime.

Association Lupin / Forage peas / Vetch very well developed and weed-free

White micro-clover with a good coverage "polluted" by a rumex

Flowering potentilla, little developed since fall 2018 and invaded by the Persian speedwell

FIGURE 14: Weed contamination according to the ability of the ground covers to quickly occupy the space

In light of these observations, it was decided to plant the second batch of perennials directly in association with a dwarf clover seedling, to assess whether this combination could be able to fill the space quickly enough to contain weed growth, thus giving time for the perennial plants to settle and expand, and then to become dominant after several vegetation cycles.

The spontaneous flora observed in the spring consisted mainly of annual dicotyledons (*Stellaria media, Veronica persica, Matricaria sp., Senecio vulgaris, Vicia sp., Cardamina hirsuta)* and some perennial dicotyledons (*Sonchus arvensis, Rumex acetosa* and *Plantago lanceolate)*. Perennial dicotyledons became predominant in the summer (*Plantago lanceolate, Sonchus arvensis, Rumex acetosa* and *Prunella vulgaris*), except in all the plots where the soil was tilled in May, which became very quickly invaded by three annual *Poaceae*: *Echinochloa crus-galli, Setaria sp., Digitaria sp*. Due to these three very aggressive weeds, none of the species planted or sown in May succeeded in growing. A series of mowings were performed several times during the summer to try to control these weeds, first to give the ground covers a chance to emerge, and next, simply to avoid them invading the entire trial with their seeds. This measure has not proven to be effective (Figures 17 and 18).

FIGURE 17: The soil of the plots planted in May 2019 was tilled in the autumn, left bare under an obscuring plastic sheeting, and tilled once again just before planting to make a fine seeding bed

FIGURE 18: Invasion of the experimental plots by barnyard grass, foxtail and crabgrass during the summer, as a result of the tillage which favored seeds emergence of these annual weeds

Among the species sown in the fall 2018, the dwarf lawn species and the « MULTIFLORE LD » green manure mix proved to be very interesting to cover the soil durably without weed contamination. Thus, the micro-dwarf white clover and the « MULTIFLORE LD » mix maintained a percentage coverage near to 100 % throughout the season, the perennial *Trifolium fragiferum* disappeared temporarily in mid-summer and reached a maximum percentage coverage by late August, and the annual white dwarf alfalfa completed its biological cycle in early June, to reappear later in early October, probably from its seeds.

Among the so-called « allelopathic » perennial species, only *Mentha spicata* was able to invade all the space during the first growing season after establishment (90% coverage reached in mid-July). *Melissa officinalis* grew more slowly, with a 45 % coverage reached at the end of August, which maintained until the end of the season. *Hieracium pilosella* was not able to prevent weed development during this first year, but it remained alive on a bottom stratus, hidden by weeds. This species remains interesting because it develops as ground-plated rosettes. It began to form very promising rosette carpets in the following mid-winter (Figure 19).

Three species – *Sagina subulata, Soleirolia soleiroli* and *Scleranthus biflorus* – were chosen for their potential interest as alternatives to lawn grass. Unfortunately, even if planted in autumn or spring, they all rapidly died after their planting, probably because they are suitable only for more shady conditions.

Hieracium pilosella planted in fall 2018 begins to form rosette carpets during winter 2019/2020

Perennial "MULTIFLORE LD" green manure remains very well developed over the winter

FIGURE 19: Coverage by two promising ground covers: views during winter after a first growing season.

Ecosystem services observed

During this first year, with an open field experiment, i.e. outside the orchard, no difference was detected between treatments, nor concerning the ground covers impact on antagonistic fauna *(Carabidae, Staphylinidae, Araneiae),* which was present on all the plots in varying degrees, nor either on earthworm abundance.

On soil samples taken one month after mowing the green manures and mulching them on the soil, without incorporation, nitrogen balance quantification gave supply amounts ranging from 5 to 73 kg N/ha, with a maximum efficiency (nitrogen supply in relation to the biomass produced) for micro-dwarf white clover and dwarf alfalfa.
With a lower nitrogen supply, the « MULTIFLORE LD » mix is also very interesting, due to its perennial growth, which will avoid the need for successive sowings, often difficult to perform under orchard conditions (Figure 19).

The use of ground covers as a source of additional income does not seem appropriate in the French context, due to their incompatibility with the pesticide calendar applied in apple orchards, even in organic systems: a toxicological risk remains for the consumer, both for aromatic or medicinal plants and for wild strawberry production. Only the herbistatic potential will therefore be researched for the plants to be settled on the tree rows.

With this purpose, *Mentha spicata, Melissa officinalis,* micro-dwarf white clover, *Trifolium fragiferum* and, to a lesser extent, dwarf alfalfa and *Hieracium pilosella*, seem to be interesting options, suitable for our local pedoclimatic context.

Green manure in full bloom of the incarnate clover: in addition to providing nitrogen, our living mulches attracts honey-gathering insects and make the landscape beautiful

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